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A TEST ON THREE MOTOR LUBRICATING-OIL ADDITIVES -- 701, 711, AND 711A

By Chang Fang-chien, Wang Yu-k'ang

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GASIFICATION OF BROWN COAL IN THE GAS PRODUCER OF GENERAL CONSTRUCTION

By Li Ch'en-hsiang

- COMMUNIST CHINA -

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A TEST ON THREE MOTOR LUBRICATING-OIL ADDITIVES -- 701, 711, AND 711A*

-Communist China-

/Following is the translation of an article by Chang Fang-chien (1728 5364 6190) and Wang Yü-k'ang (3769 5940 1660), of the Ministry of Petroleum Industry's Refinery No. 7, in Jan-liao Hsüeh-pao ('Acta Focalia Sinica', or Journal of Fuels), Vol. 4, No. 2, pp. 140-156, April 1959, Shanghai/

Abstract

Three different additives -- 701, 711, and 711A -- of barium salt of alkyl-phenol type for motor lubricating oil have been synthesized, and their effects on the performance of motor lubricants produced from the Soviet-produced Second Baku Crude-No. 15 (for motor vehicles) and Yumen Crude-No. 10 (for motor vehicles), have been investigated. Their viscosity-temperature characteristics, their lubricity and anti-corrosive properties, their anti-oxidation and detergent properties have been evaluated. The motor lubricants with the above three additives added have also been tested on a single-cylinder gasoline engine. For purposes of comparison, Soviet-produced diesel lubricant DP-14 and additive (Russian) -- AzNII-TsIATNIM-1 (Azerbaydzhanskiy Nauchno-issledovatel'nyy institut--Tsentral'nyy Nauchno-issledovatel'nyy Institut Aviatsionnykh topliv i masel-1 -- Azerbaydzhan Scientific Research Institute and Central Scientific Research Institute of Aviation Fuels and Lubricants-1) have been selected for parallel runs.

Test results indicate that additive 701 improves the special characteristics of the viscosity-temperature of the lubricating oil slightly, but additives 711 and 711A produce a somewhat unfavorable effect. Additive 711A shows the

* Received 15 October 1958.

best results on lubricity improvement. Also, as regards anti-corrosiveness, additive 711A produces significant results with the No. 10 motor oil of Yumen origin. All three additives -- 701, 711, and 711A -- show good anti-oxidation properties below 250° C, but deteriorate rapidly at higher temperatures, such that the additive effect becomes almost nil under the oxidation conditions present at 300° C. For detergent effect, additive 711A improves the Second Baku Crude-No. 15 from grade 6 to grade 1 on the model-engine test.

Preliminary engine tests of motor lubricants containing additive 711A -- on a single-cylinder gasoline engine -- prove that less acid is formed, viscosity is lowered, less deposit is found on the pistons and rings, and less corrosion is observed.

Introduction

During the last twenty years, salts of carboxylic acid, sulfonic acid and alkyl-phenols have been used extensively as additives for improving the performance of motor lubricating oils(1). Most of these types of additives have lessened the effects of oxidation on lubricating oils (anti-oxidation), reduced corrosion -- especially in the corrosion of non-ferrous metals and their alloys -- (anti-corrosion), and also reduced carbon deposits on various parts of the engine (detergency, or deflocculant property). Among these additives, the barium salts of alkyl-phenols have been extensively adopted by industry.

In order to improve the quality of our lubricants and to produce motor lubricants for high-speed diesel engines adequate to meet the needs of socialist construction, we have studied and produced additives with improved motor lubricant operational characteristics(2). Three kinds of more effective additives -- designated as 701, 711, and 711A -- were produced on a trial-run basis in 1957. 701 is barium salt of sulfonated alkyl-phenol; 711 is another type of barium salt of sulfonated alkyl-phenol; 711A is alkyl-phenol barium salt.

In order to determine whether or not these three types of additives are capable of improving the performance of motor lubricants, we have carried out laboratory experiments with the assistance of the Institute of Petroleum -- Academia Sinica -- in an effort to determine their effects on the viscosity-temperature indices, lubricity, anti-corrosion, anti-oxidation and detergent properties, et cetera, of the lubricants. Comprehensive evaluation tests have also been undertaken on a Type-1103 single-cylinder engine using

samples with and without the additives.

For the comparison, a Soviet-produced additive -- the AzNII-TsIATNIM-1 -- and a diesel oil motor lubricant -- DP-14 -- also have been evaluated.

Experimental Data

1. Physical and chemical properties of motor lubricants under evaluation. The basic samples under evaluation were selected and manufactured by Refinery No. 7 from the specially-processed Second Baku Crude-No. 15 and Yumen Crude-No. 10. The amount of additive contained in both samples was approximately 3%.

The physical and chemical properties of the original lubricants -- with and without the additives -- are reproduced in Table 1 (see pages 4 and 5).

It will be noted from the data in Table 1 that the properties of Second Baku Crude-No. 15, after the addition of additives 711A, 711, 701, or AzNII-TsIATNIM-1, meet the specific requirements of the Soviet diesel lubricant DP-14 (GOST 5304-54). If only additive 711A is added, then the solidifying point is not up to specifications.

Yumen Crude-No. 10 meets all the specifications of Soviet diesel lubricant DP-11 (GOST 5304-54) after the addition of the above-mentioned additives, except in respect to the solidifying point, viscosity and viscosity ratio.

It is also noted from these results that both additives 701 and AzNII-TsIATNIM-1 have similar effects in respect to lowering the solidifying point, while neither 711 nor 711A has such effects. On the contrary, the solidifying point of the oil sample was raised by 2-4^{o} after the addition of additive 711A. This is related primarily to the length of the alkyl group in the molecule of the additive.

2. Viscosity-temperature characteristics of motor lubricants under evaluation. In speaking of the properties of lubricants, the particular characteristics of viscosity-temperature form an important criteria. Viscosity-temperature factors determine whether or not the lubricant can be quickly conveyed to the friction points or to the surfaces when the engine is started at a low temperature. It also indicates whether or not an adequate oil level can be maintained in the high-temperature region between the piston rings and the cylinder wall. It is obvious that these factors are directly related to engine wear.

Figure 1 shows the viscosity-temperature curves -- ranging from 10^{o} to 150^{o} -- for Second Baku Crude-No. 15 and diesel lubricant DP-14, with and without additives 711A,

Lubricant Sample	Dynamic Viscosity (Centistokes) 50°C	100 C	Viscosity Ratio	Acidity (mg. KOH/g. Sample)	Residual Carbon (%)	Ash Content (%)
DP-14/Standard (GOST 5304-54)	—	13.5—15.5	Not greater than 7.75	Not greater than** 0.10	Without additive not greater than 0.55	Not less than* 0.25
Second Baku Crude-No.15	119.5	15.78	7.56	0.039	0.398	0.003
Same, with 3% 711A	110.3	15.58	7.65	Alkaline	1.048	0.623
Same, with 3% 711	120.8	15.63	7.74	Alkaline	0.834	0.305
Same, with 3% 701	101.8	14.71	6.92	0.005	0.605	0.125
Same, With 3% AzNII-TsIATNIM-1	98.8	14.66	6.75	0.023	0.617	0.123
DP-14	94.3	14.88	6.87	Alkaline	1.158	0.292
DP-11/Standard (GOST 5304-54)	—	10.5—12.5	Not greater than 6.5	Not greater than** 0.1	Without additive, not greater than 0.4	Not less than 0.25
Yumen Crude-No.10	99.4	13.02	7.62	0.085	0.097	0.0044
Same, with 3% 711A	100.6	13.12	8.0	Alkaline	0.878	0.792
Same, with 3% 711	98.6	12.80	7.70	0.002	0.430	0.285
Same, with 3% 701	99.7	13.40	7.43	0.012	0.243	0.120
Same, With 3% AzNII-TsIATNIM-1	98.0	13.02	7.54	0.024	0.225	0.111

* Requirement for ash content for DP-14, 0.12 when additive AzNII-TsIATNIM-1 is DP-11, also not less than 0.12.

** Requirement for acid content for DP-14, 0.22 when additive AzNII-TsIATNIM-1 is DP-11. not less than 0.20.

Mechanical Sediment (%)	S Content (%)	H_2O Content (%)	Flash Point (°C.)	Solidifying Point (°C)	H_2O-Soluble Acid Anhydride	Binkovitch Corrosion ($g./m^2$)	High Temp. Oxidation Stability (Paback)-(Min. 250°C)
NOT GREATER THAN 0.01	—	TRACE	NOT LOWER THAN 210	NOT HIGHER THAN −10	WEAK ALKALINE	NOT GREATER THAN 13	NOT LESS THAN 25
0.0029	1.38	NONE	249	−6	NEUTRAL	1.4	31
0.0017	1.34	NONE	247	−2	ALKALINE	4.1	55
0.0029	1.57	NONE	242	−10	WEAK ALKALINE	1.4	58
0.0022	1.44	NONE	245	−22	NEUTRAL	6.5	43
0.0032	1.38	NONE	261	−26	NEUTRAL	—0.5	33
0.005	0.85	TRACE	215	−2	ALKALINE	13.4	35
NOT GREATER THAN 0.01	—	NONE	NOT LOWER THAN 190	NOT HIGHER THAN −15	WEAK ALKALINE	NOT GREATER THAN 13	NOT LESS THAN 25
0.0009	0.12	NONE	236	−8	NEUTRAL	69	30
0.0017	0.80	NONE	238	−6	ALKALINE	2.6	46
0.0015	0.49	NONE	230	−10	WEAK ALKALINE	27.4	45
0.0016	0.37	NONE	236	−28	NEUTRAL	19.7	42.5
0.00017	0.31	NONE	230	−26	NEUTRAL	1.6	40

not less than
present; for

not less than
present; for

Table 1. Physical and Chemical Properties of Motor Lubricants Under Evaluation.

711, 701, or AzNII-TsIATNIM-1. Figure 2 illustrates the viscosity-temperature curves for Yumen Crude-No. 10, with and without the above additives. It can be seen from Figure 1 that the viscosities of each of the oils are basically the same when the temperature is over 100°. However, viscosities of lubricants in which have been added additives 711 and 711A, tend to increase when the temperature drops. Similar effects are noted in Figure 2. Therefore, it is necessary to study further the extent of the

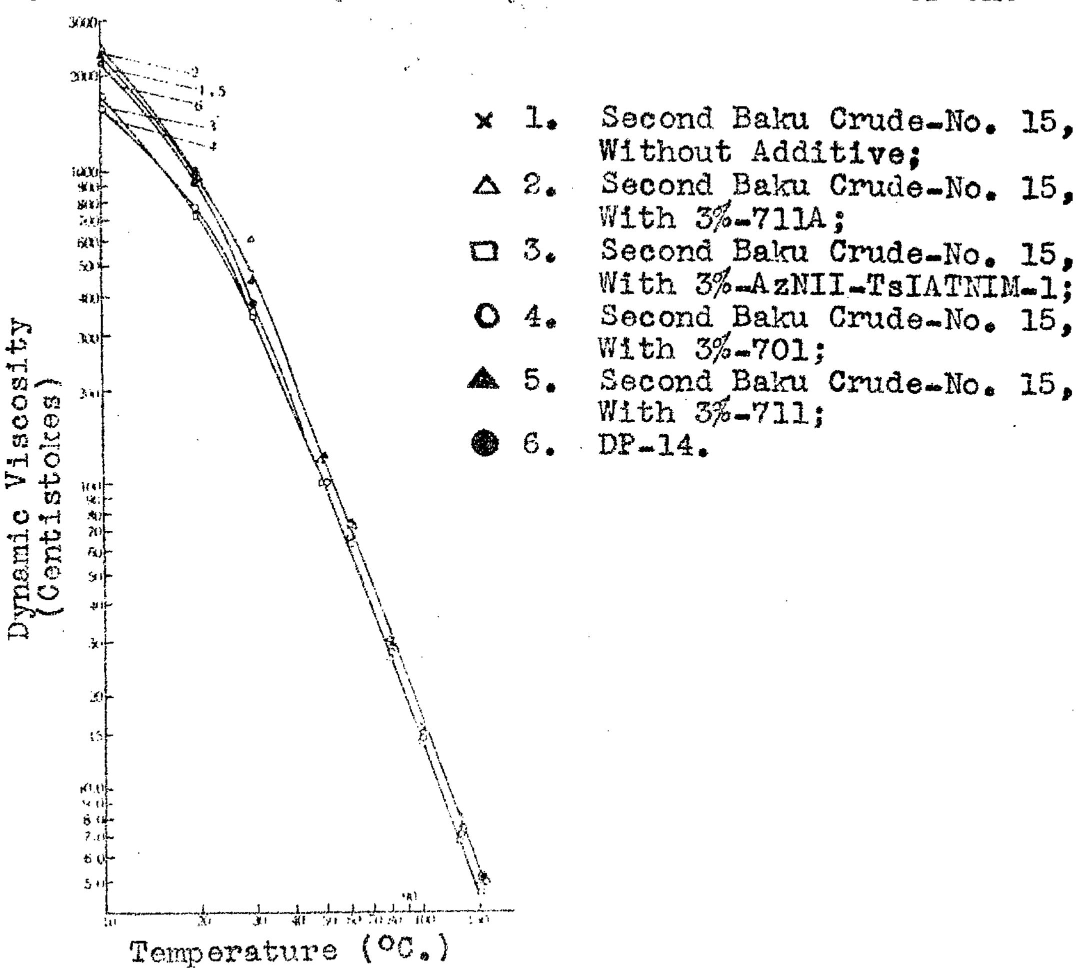


Figure 1. Viscosity-Temperature Curves of Second Baku Crude-No. 15 -- With and Without Additives.

effects of additives 711 and 711A as they relate to the lubricant fluidity at low temperatures, fluidity at delimiting temperatures, and at the lowest temperature in starting an engine cold.

It has been found that both Soviet additives 701 and

AzNII-TsIATNIM-1 slightly improve the viscosity-temperature properties of the lubricants.

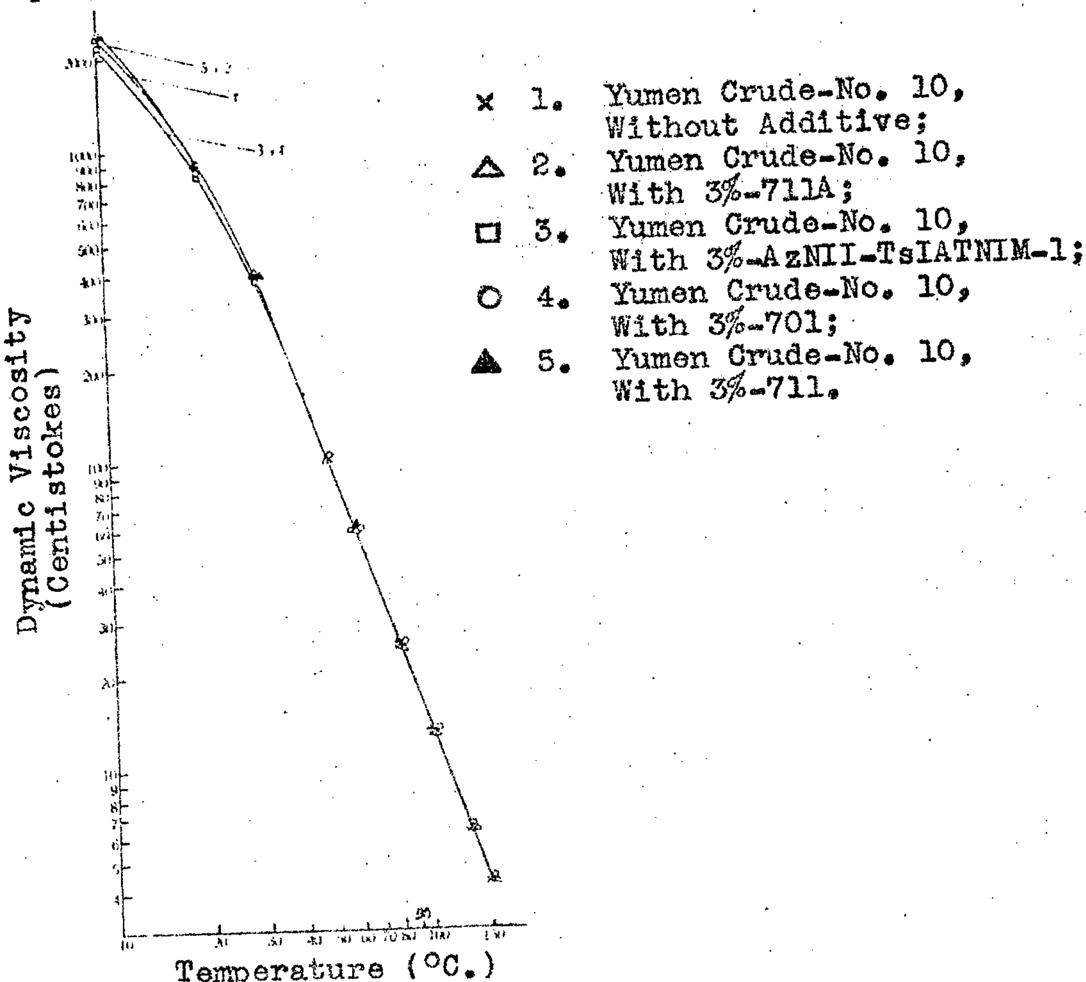


Figure 2. Viscosity-Temperature Curves of Yumen Crude Oil-No. 10 -- With and Without Additives.

3. Lubricity -- or lubricating properties -- of motor lubricants under evaluation. Tests were carried out with Second Baku Crude-No. 15 -- with and without additives -- and with diesel lubricant DP-14, using a four-ball friction and wear machine. Test conditions were as follows:

Maximum speed (ball):	1500 rpm
Ball diameter:	1/2 inch
Test period:	60 seconds
Lubricant temp., before test:	Room temp.

The total loads carried on disrupture of the lubricant oil films are tabulated in Table 2.

Table 2.

Lubricant Sample	Total Load on Disrupture of Film -- kg.	Wear in Diameter on Film Disrupture (mm.)
Second Baku Crude-No. 15	65	0.29
" " ", + 3%-711A	90	0.42
" " ", + 3%-711	79	0.41
" " ", + 3%-701	70	0.42
" " ", + 3%-AzNII-TsIATNIM-1	72	0.44
DP-14	82	0.43

Figure 3 shows the relationship between the total load and the ball wear -- in diameter. It can be seen from Figure 3 and Table 2 that all the additives are capable of increasing the oil film strength. Among the additives, the additive 711A increases the oil film strength to the greatest extent -- an increase of 25 kg. over the load carried by the crude sample without the addition of an additive. This figure exceeds even the oil film strength of the diesel lubricant DP-14.

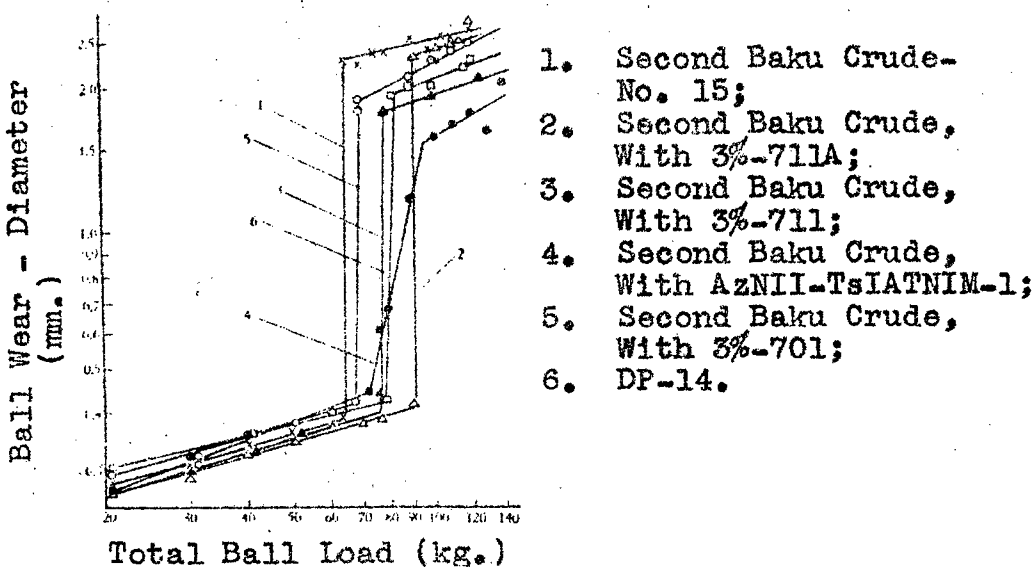


Figure 3. Total Load-Ball Wear (in diameter) Curves.

Furthermore, it is shown by Figure 3 that the wear

(in diameter) in the case of a sample with additive 711A, is the lowest before the disruption of oil film (when the total load is less than 90 kg.), while wear is greatest in the case of diesel lubricant DP-14. Consequently, it can be concluded that additive 711A possesses good lubricating properties.

It can also be seen from Figure 3, however, that the additive loses its effect as soon as the oil film is disrupted, as in the case of the sample with additive 711A. Thus, the wear -- in diameter -- is similar to that which resulted from samples without additives added.

4. Anti-corrosion properties of motor lubricants under evaluation. In recent years, the development of internal combustion engines has demanded more from lubricants -- especially from the standpoint of anti-corrosion requirements. This is particularly true in the case of diesel engines where bearing metals have been changed from babbitt to copper-lead or cadmium-silver. Since lead, cadmium, et cetera, and other non-ferrous metals of such newer alloys, are easily soluble in oxidized lubricants[3], the anti-corrosion properties of lubricants becomes all the more significant.

In order to determine whether or not the samples under evaluation can be used in the diesel engine, the determination of their anti-corrosion properties appears to be highly significant. The Binkovitch method of evaluation (GOST 5162-49) was adopted and the test results are shown in Table 3.

Table 3.

Lubricant Sample	Corrosion ($g./m^2$)
Second Baku Crude-No. 15	1.4
Same, With 3%-711A	4.1
Same, With 3%-711	1.4
Same, With 3%-701	6.5
Same, With 3%-AzNII-TsIATNIM-1	-0.5
DP-14	13.4
Yumen Crude-No. 10	69.0
Same, With 3%-711A	2.6
Same, With 3%-711	27.4
Same, With 3%-701	19.7
Same, With 3%-AzNII-TsIATNIM-1	1.6

Anti-Corrosion Property (Pb Sheet) Evaluation By Binkovitch Method.

The results of the corrosion tests indicate that the No. 15 Motor Oil itself -- produced from the Second Baku Crude -- has good anti-corrosion properties. The addition of either the 701, 711, or 711A additives, though, slightly increases its corrosiveness. However, when AzNII-TsIATNIM-1 is added, a negative value is obtained in the corrosion test. Since this additive is capable of forming a strong, firm protective film on the metal surface, the negative value actually represents the weight of this film.

The anti-corrosion properties of Second Baku Crude-- either with or without the above additives -- far exceeds that of the diesel lubricant DP-14.

The corrosion resulting from the No. 10 Motor Oil -- produced from the Yumen Crude -- reaches 69 g./m^2. This is considerably lessened after the addition of either 711A or AzNII-TsIATNIM-1 (see Table 3), and far exceeds the requirements of DP-11 (GOST 5304-54). Although corrosion is also lowered by the addition of 701 and 711, the oil -- on the whole -- however, does not meet the specifications of DP-11.

In comparing these additives, it can be concluded that both AzNII-TsIATNIM-1 and 711A possess good anti-corrosion properties, while additives 701 and 711 are less effective. This is especially obvious when either one of these additives is added to Yumen Crude-No. 10, in which case the resulting lubricant is rendered unfit for diesel engines. Therefore, the sulfonation conditions during the manufacture of these additives should be improved in order to raise their anti-corrosion properties.

Similarly, the above conclusion can be drawn from Figures 4 and 5 -- plotted according to data tabulated in Table 4 -- on page 11.

It is noteworthy that the total corrosion of the lead sheet over a 50-hour testing period -- during which time the corrosion was checked once every five hours -- was generally greater than that determined only once at the end of the 50-hour period (see Tables 3 and 4). It may also be noted here that the amount of corrosion in the case of additive AzNII-TsIATNIM-1 is greater than those with 711A.

Conceivably, a firm protective film was not formed on the metal surface within five hours (in the course of the corrosion test); thus, the film residue was probably rinsed off when the metal sheet was withdrawn and washed with benzene before weighing. Consequently, during the next five-hour test period, the metal surface came into direct contact with the oxidized lubricant and, thereby, the corrosion was increased.

The anti-oxidation property is poorer in the AzNII-

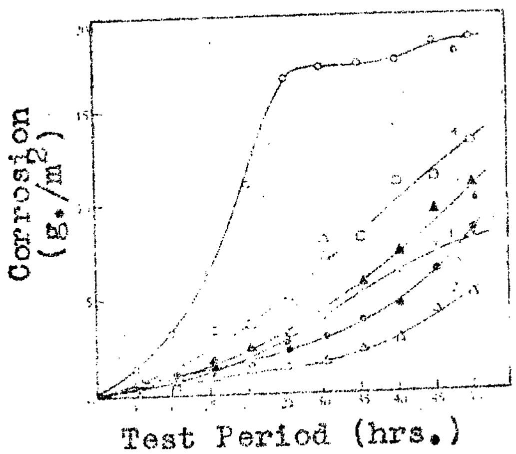


Figure 4.

1. Second Baku Crude-No. 15;
2. Same, With 3%-711A;
3. Same, With 3%-711;
4. Same, With 3%-701;
5. Same, With 3%-AzNII-TsIATNIM-1;
6. DP-14.

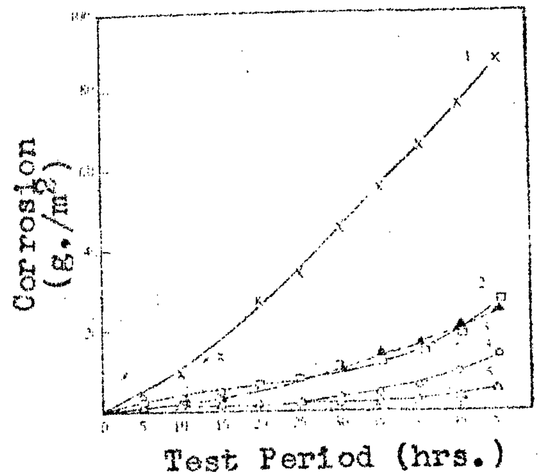


Figure 5.

1. Yumen Crude-No. 10;
2. Same, With 3%-701;
3. Same, With 3%-711;
4. Same, With 3%-AzNII-TsIATNIM-1;
5. Same, With 3%-711A.

Table 4. Results of Corrosion Test Determined Every 5 Hours (Binkovitch).

Lubricant Sample	Lubricant Corrosiveness (g./m²) 5 hour Intervals									
	5	10	15	20	25	30	35	40	45	50
Second Baku Crude - No. 15	0.2	0.8	1.5	1.8	2.84	3.80	5.30	6.20	7.50	8.70
Same - With 3% - 711A	0.1	0.8	0.9	1.2	1.30	1.60	2.20	2.70	4.20	5.00
Same - With 3% - 711	0.4	1.0	1.7	2.3	2.8	3.0	5.6	7.3	9.5	10.7
Same - With 3% - 701	0.6	0.5	3.4	3.7	4.8	7.2	8.2	[illegible]	11.3	13.1
Same - With 3% - AzNII-TsIATNIM-1	0.5	1.3	1.5	1.5	2.4	3.0	3.8	4.5	6.1	8.4
DP-14	1.3	3.2	6.5	11	16.6	17.3	17.5	17.6	18.6	18.8
Yumen Crude - No. 10	4.3	9.5	13.6	27.6	34.5	45.6	55.5	65.8	76.2	87.7
Same - With 3% - 711A	0.6	1.4	1.1	1.2	1.3	1.6	1.8	2.4	3.5	5.3
Same - With 3% - 711	0.9	1.3	2.4	7.5	—	10.2	14.2	16.5	21.2	25.4
Same - With 3% - 701	1.4	2.5	4.8	6.7	8.9	10.3	12.1	16.0	20.1	27.8
Same - With 3% - AzNII-TsIATNIM-1	0.5	0.6	1.0	1.2	1.9	3.2	4.7	6.2	9.6	14.1

TsIATNIM-1 than it is in the additive 711A. When it is incapable of forming a protective film on the metal surface, the metal comes into contact with the more extensively oxidized lubricant. Thus, its anti-corrosion property is poorer than that of 711A.

It should be pointed out that results of parallel runs in determining corrosion properties of Second Baku Crude-No. 15 -- without additives -- have been unsatisfactory and were obtained with great difficulties using the Binkovitch instruments.

5. Anti-oxidation properties of motor lubricants under evaluation.

a) Oxidation test under thin oil-layer conditions. The oxidation characteristics test with thin oil-layers is designed to evaluate the complex changes of the oil -- on the surface of the metal -- under the effects of air and high temperatures. This experiment was intended to explain the possible changes and activity of the lubricant in the ring-belt area or other high-temperature regions of the engine. We adopted -- for our tests -- the method proposed by K. K. Pabock (GOST 4953-49) for the determination of oxidation stability of lubricants at high temperatures.

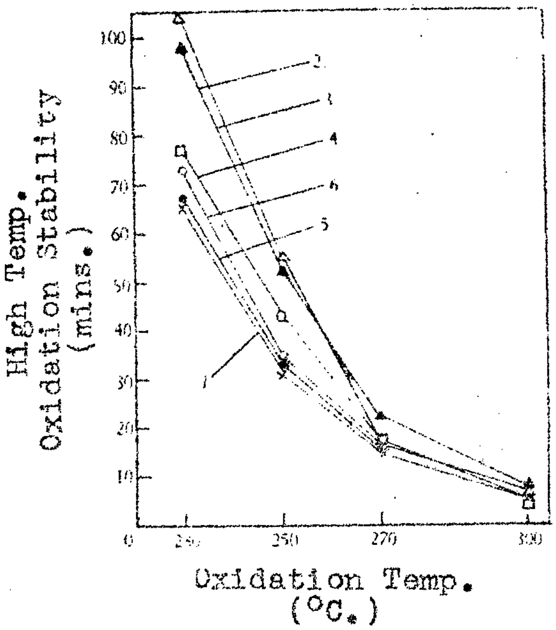
According to Pabock, oxidation stability at high temperatures might indicate the lubricity in the engine ring-belt area on judging the extent of ring-belt area charring or lacquer deposits on the engine parts[4]. Results of Pabock's experiments also confirmed the fact that oxidation stability at high temperatures is definitely related to piston ring stickiness[3] in the engine. This relationship has also been confirmed in our studies.

The oxidation stability properties of various lubricants at temperatures of 230°, 250°, 270°, and 300°, were determined and the results are shown in Table 5, and in Figures 6 and 7 (see page 13).

These results indicate that additive 711A is effective in combating oxidation in conditions under 250°, whether added to Second Baku Crude-No. 15 or to Yumen Crude-No. 10. Its anti-oxidation characteristics, however, quickly deteriorate as soon as the temperature rises, until its effects become almost nil at 300°. Since it is common in diesel engines for the ring-belt area to reach a temperature of 300° (3, 4), the stability of 711A at high temperatures should be improved.

Additive 711, on the other hand, displays a comparatively better oxidation stability at temperatures above 250°.

Among these additives, the anti-oxidation properties



1. Second Baku Crude-No. 15;
2. Same, With 3%-711A;
3. Same, With 3%-711;
4. Same, With 3%-701;
5. Same, With 3%-AzNII-TsIATNIM-1;
6. DP-14.

Figure 6.

1. Yumen Crude-No. 10;
2. Same, With 3%-711A;
3. Same, With 3%-711;
4. Same, With 3%-701;
5. Same, With 3%-AzNII-TsIATNIM-1.

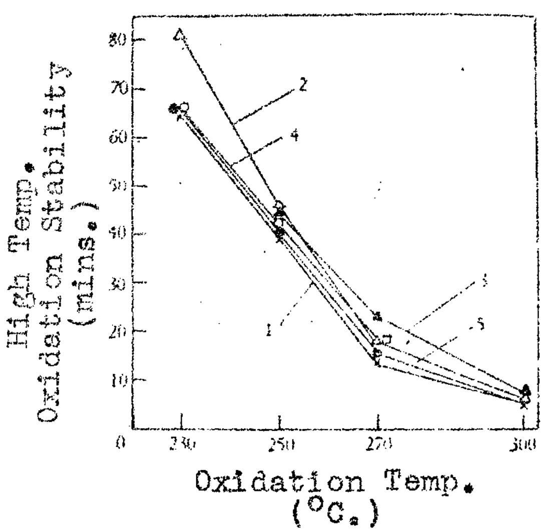


Figure 7.

Lubricant Sample	High Temp. Oxidation Stability (mins)			
	230°	250°	270°	300°
Second Baku Crude-No. 15	65	31	14.5	5.5
Same, With 3%-711A	104	55	16	6
Same, With 3%-711	98	53	22.5	8
Same, With 3%-701	77	43	17	5
Same, With 3%-AzNII-TsIATNIM-1	67	33	15	5.5
DP-14	73	35	16	5.5
Yumen Crude-No. 10	65	39	13.5	5
Same, With 3%-711A	81	46	18	7
Same, With 3%-711	--	45	23	7.5
Same, With 3%-701	66	42.5	18	6.5
Same, With 3%-AzNII-TsIATNIM-1	66	40	15.5	5

Table 5.

of AzNII-TsIATNIM-1 is the most deficient.

The oxidation stability characteristics of both Second Baku Crude-No. 15 and Yumen Crude-No. 10 satisfy the requirements of high-speed diesel lubricants -- DP-14 and DP-11 -- at 250°, even without additives, and far exceed these specifications after the addition of additives.

b) Oxidation test under thick oil-layer conditions. Crankcase oil oxidation falls under this category. It has been pointed, among others by H. E. Tchernoskoff, that oxidation proceeds with the formation of acids, resins, and asphalt materials(5). In other words, acidity, viscosity, et cetera, of the lubricants increase as oxidation progresses. Our laboratory experiments on thick oil-layers were conducted under the following oxidation conditions:

Amount of test sample:	40 ml.
Oxidation temperature:	200°
Rate of Aeration (input):	15 lit./hr.
Oxidation period:	12 hours (in two runs)

Table 6 shows the viscosity, acidity, and the amount of residual coke for the sample before and after oxidation.

Table 6. Viscosity, Acidity, Residual Carbon of Samples Before and After the Thick Oil-Layer Oxidation Test.

Lubricant Sample	50° Dynamic Viscosity (Centistokes)		100° Dynamic Viscosity (Centistokes)		Acidity (mg. KOH/g. oil)		Residual Carbon (%)	
	Before	After	Before	After	Before	After	Before	After
Second Baku Crude-No-15	119.5	239.3	15.78	26.14	0.039	2.168	0.598	3.38
Same, with 3%-711A	119.3	198.1	15.58	22.59	Alkaline	2.370	1.043	3.09
Same, with 3%-711	120.8	---	15.63	33.49	Alkaline	2.020	0.834	5.00
Same, with 3%-701	101.8	215.0	14.71	24.88	0.005	2.010	0.605	3.69
Same, with 3%-AzNII-TsIATNIM-1	98.8	240.5	14.66	26.28	0.023	2.320	0.617	4.02
DP-14	94.3	216.3	14.83	26.91	Alkaline	2.710	1.158	3.97
Yumen Crude-No.10	99.4	128.8	13.02	18.79	0.035	2.44	0.097	1.95
Same, with 3% 711A	100.6	135.3	13.12	17.07	Alkaline	1.78	0.878	2.85

Judging by the changes in viscosity and residual carbon values -- before and after oxidation (see Table 6) -- it is found that additive 711A possesses relatively good anti-oxidation properties. 711A, however, with respect to acidity -- before and after oxidation -- displays very poor anti-oxidation properties; whereas, both 711 and 701 are superior in this respect.

The anti-oxidation properties of additive AzNII-TsIATNIM-1, compared with our additives, is poorer in either viscosity, acidity, or amount of residual carbon.

Table 7. Binkovitch Method of Acidity Determination After Oxidation.

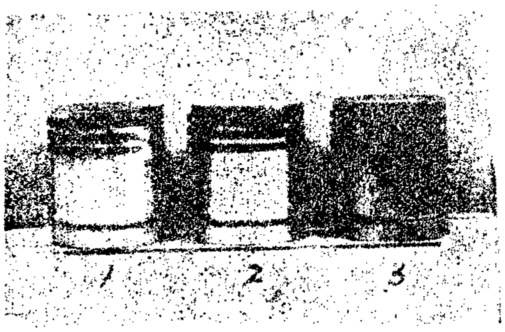
Sample	Acidity Value (mg. KOH/g. oil)
Second Baku Crude-No. 15	0.66
Same, With 3%-711A	0.06
Same, With 3%-711	0.70
Same, With 3%-701	0.65
Same, With 3%-AzNII-TsIATNIM-1	0.57
DP-14	0.86
Yumen Crude-No. 10	0.28
Same, With 3%-711A	0.09
Same, With 3%-711	0.49
Same, With 3%-701	0.48
Same, With 3%-AzNII-TsIATNIM-1	0.46

The acidity values of the samples -- after subjection to the Binkovitch corrosion test -- are tabulated in Table 7 (above). This technique is also a type of thick oil-layer oxidation test, except that the temperature of oxidation and the degree of oxygen contact are much more moderate than those described above. The data described in Table 7 shows that 711A is an effective anti-oxidant in keeping the acidity of the sample at a low lever after oxidation. This observation does not contradict the results tabulated in Table 6. It does, however, explain the fact that under high temperatures and vigorous reaction conditions additive 711A is easily consumed. On the other hand, at lower temperatures, additive 711A maintains its excellent anti-oxidation properties. Such an explanation is in accord with the high-temperature oxidation stability data (Table 4) obtained by the Pabock method.

6. Detergency (defluocculant property) of motor lubricant samples under evaluation. Various hypotheses

have been proposed to explain the detergency mechanism -- defluocculant property -- of additives, from whence have arisen numerous methods for the determination of this property. Among these, the results obtained by the P.3 B. Method (GOST 5726-51) -- proposed by K. K. Pabock -- are closer to those obtained from actual engine performance[3].

Figure 8. Photograph of Pistons After P.3 B. Test.



1. DP-14 Diesel Lubricant;
2. Second Baku Crude-No. 15, With 3%-711A;
3. Second Baku Crude-No. 15, Without Additive.

We have conducted tests on detergency characteristics by using the P.3 B. equipment built by the Institute of Petroleum, Academia Sinica. However, comparison tests only on Second Baku Crude-No. 15 -- with and without the additive 711A -- and on diesel lubricant DP-14, were conducted -- due to mechanical difficulties.

Conditions of the standard test method (GOST 5726-51)[6] were adopted, except that the engine speed was altered to 1500 rpm.

Figure 8 shows the test results for the three samples. Detergency properties of Second Baku Crude-No. 15 -- without additives -- were the poorest (classified as grade 6 by evaluation). This conclusion agrees with the results obtained by Nilchiky in a similar study of this same lubricant[7].

However, its detergency can be increased to grade 1 after the addition of additive 711A. Detergency of diesel lubricant DP-14 was also found to be grade 1.

7. Comprehensive evaluation of the general properties of motor lubricants as determined by tests conducted on a Type-1103 single-cylinder engine. Low-powered single-cylinder engines have been used extensively in the evaluation of motor lubricant performance.

The Type-1103 single-cylinder gasoline engine is manufactured by Liu-chou Machinery, Kwangsi (Province).

The main purpose of such tests is to compare the

respective wear-reducing properties, anti-oxidation, anti-corrosion, carbon deposit reduction properties, detergency, et cetera, of the various motor lubricants in engine test runs. The test method which utilizes this type of engine in the evaluation of motor lubricant performance was treated in a special report which also discussed its ability to be reproduced and its recurrent nature[8].

In evaluating the corresponding properties of diesel lubricants in their performance on a single-cylinder gasoline engine, rigid test conditions were adopted and the operating conditions described by G. H. J. Simmons[9], in the evaluation of diesel engine motor lubricants on a similar type of engine were studied before the conditions described below were put forth. The conditions adopted by Fan Yu (5400 3558) and Tang Hung-hsin (8096 7703 6580), in their evaluation of aviation lubricating oils using a Type-1103 single-cylinder engine, were also compared[10].

The principal operating conditions employed in our tests were as follows:

Test period:	80 hours
Engine load:	1.5 0.1 hp
Temp. of water for cooling,	
inlet :	95-105°
outlet:	120-125°
Engine speed (rpm):	150 20 rpm
Temp. of lubricant:	100-105°
Air temp. - inlet:	30 1°

The lubricated surface was examined every 10 hours, and fresh lubricant was added.

Samples drawn after testing for 40 hours, and those taken at the end of the test were analyzed for their iron content and for physical and chemical properties.

Determinations were also made of the amount of carbon deposit on the top of the piston, the amount of lacquer-like material deposited on the piston, stickiness and wear on the piston rings, et cetera, after the test.

The fuel used in the test was straight distillation gasoline from Yumen Crude-No. 10 -- without the addition of lead.

In order to determine, or prove, that the results obtained in testing the various oil samples -- useing the same engine -- were comparable, tests were repeated -- starting with the first sample -- after the tests on the entire series of samples was completed. If the results of the first test can be duplicated in the second test, then it can be shown that the mechanical variations of the en-

gine are not great. Thus, it was found that these results could be closely duplicated.

Table 8 shows the test sequence of the samples. Tests were undertaken with both Second Baku Crude-No. 15 and Yumen Crude-No. 10. The tests conducted with Yumen Crude-No. 10, however, in order to prolong the life of the engine, were only run in conjunction with the additive 711A -- with and without the additive.

Table 8. Test Sequence of Lubricant Samples.

Test Sequence	Lubricant Sample
Run No. 1	Second Baku Crude-No. 15
" " 2	Same, With 3%-711A
" " 3	Same, With AzNII-TsIATNIM-1
" " 4	Same, With 3%-711
" " 5	Same, With 3%-701
" " 6	DP-14
" " 7	Second Baku Crude-No. 15
" " 8	Yumen Crude-No. 10
" " 9	Same, With 3%-711A

Table 9 (see page 19) is a tabulated analysis of the results of samples before and after 40 hours and 80 hours, respectively, from tests conducted on the single-cylinder engine.

Figures 9 and 10 (see page 20) show the changes of the samples in their viscosities; changes in acidity in the test runs are shown in Figures 11 and 12 (see page 21).

It is readily seen that among these additives, 711A possesses the best oxidation-inhibiting property which, however, is short-lived since its oxidation stability at high temperatures deteriorates rapidly as its period of application lengthens, as shown in Figure 13 (see page 22).

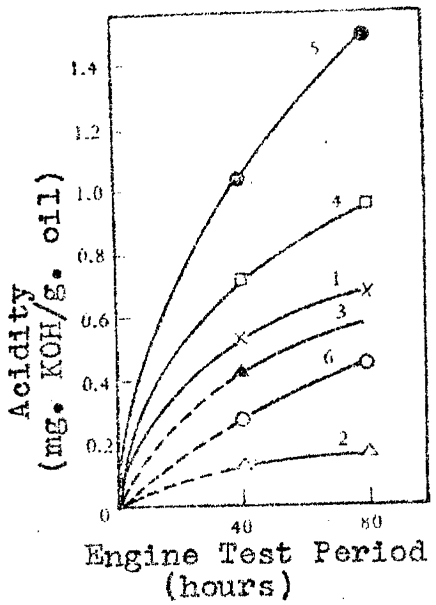
In evaluating the ability of lubricants to effectively resist carbonaceous materials, n carbon is taken to represent piston deposit index. Its value is equal to the gram-weight of carbon deposit on the top of the piston.

The detergency characteristic of the sample, n_{clean}, is expressed by the algebraic sum of $n^{*}_{lacquer}$, which grade number is determined by the color of the lacquer film on the piston, and n_{ring}, the piston ring stickiness index:

* Refer to (8) for details concerning definitions and methods of evaluating these indices.

Sample	Test Period (hours)	Sp.Gr. (d_4^{20})	Dynamic Viscosity (Centistokes) 50°	Dynamic Viscosity (Centistokes) 100°	Viscosity Ratio (50/100)	Acidity (mg. KOH/g. oil)	Residual Carbon (%)	S Content (%)	High Temp. Oxidation Stability (mins.)
Second Baku Crude-No. 15	0	0.9123	119.5	15.78	7.56	0.039	0.298	1.38	31
	40	0.9168	147.0	18.10	8.12	0.53	1.10	1.37	29
	80	0.9172	155.4	18.87	8.25	0.67	1.20	1.38	27.5
Same. With 3% 711A	0	0.7157	119.8	15.58	7.65	Alkaline	1.048	1.34	55
	40	0.9194	136.4	17.6	7.74	0.18	—	1.28	—
	80	0.9216	142.5	17.86	8.0	0.16	1.77	1.24	40
Same. With 3% 711	0	0.9151	120.8	15.63	7.74	Alkaline	0.834	1.57	53
	40	0.9164	142.4	17.52	8.13	0.41	1.230	1.24	50
	80	0.9208	150.7	18.28	8.24	0.58	1.474	1.25	47
Same. With 3% 701	0	0.9100	101.8	14.71	6.92	0.005	0.605	1.44	43
	40	0.9171	133.8	16.99	7.92	0.71	1.30	1.38	40
	80	0.9186	150.9	18.49	8.16	0.96	1.68	1.20	36
Same, With 3% AzNII-TsIATNIM-1	0	0.9112	98.8	14.66	6.75	0.028	0.617	1.38	33
	40	0.9161	129.1	17.01	7.58	1.04	1.34	1.17	—
	80	0.9186	147.2	18.44	8.01	1.50	1.76	1.37	31
DP-14	0	0.8981	94.3	14.83	6.37	Alkaline	1.158	0.85	35
	40	0.9012	127.6	18.30	7.0	0.28	1.97	0.80	34
	80	0.9065	146.4	19.91	7.34	0.45	1.68	0.65	32
Yumen Crude-No. 10	0	0.9087	19.4	15.02	7.62	0.035	0.097	0.12	39
	40	0.9179	474.76	14.32	8.12	0.44	0.547	0.18	38
	80	0.9133	117.15	14.54	8.06	0.60	0.750	0.19	36
Same. With 3% 711A	0	0.9134	100.6	13.12	8.0	Alkaline	0.878	0.30	46
	40	0.9171	115.1	14.23	8.08	0.059	1.240	0.24	42.5
	80	0.9185	120.5	14.73	8.17	0.106	1.495	0.24	42

Table 9. Analysis of Results of Lubricant Samples After Tests on Single-Cylinder Engine.



1. Second Baku Crude-No. 15;
2. Same, With 3%-711A;
3. Same, With 3%-711;
4. Same, With 3%-701;
5. Same, With 3%-AzNII-TsIATNIM-1;
6. DP-14.

Figure 9. Acidity of Lubricant Samples After Engine Test.

1. Yumen Crude-No. 10;
2. Same, With 3%-711A.

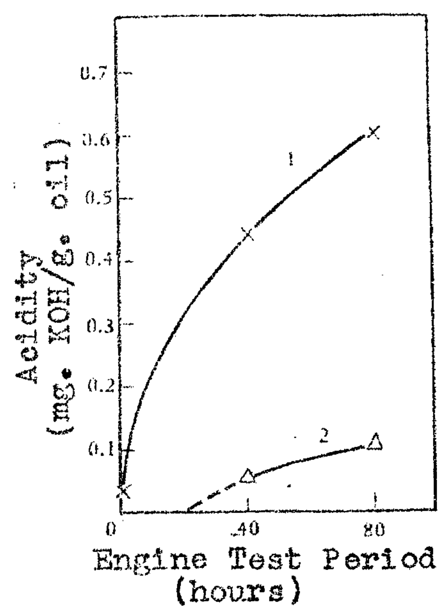


Figure 10. Acidity of Lubricant Samples After Engine Test.

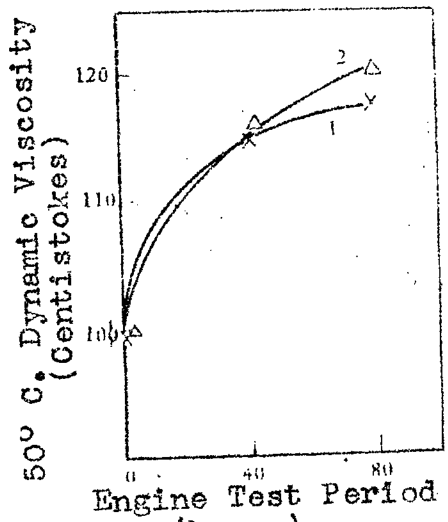


Figure 11. Viscosity of Lubricant Sample After Engine Test.

1. Yumen Crude-No. 10;
2. Same, With 3%-711A.

1. Second Baku Crude-No. 15;
2. Same, With 3%-711A;
3. Same, With 3%-711;
4. Same, With 3%-701;
5. Same, With 3%-AzNII-TsIATNIM-1;
6. DP-14.

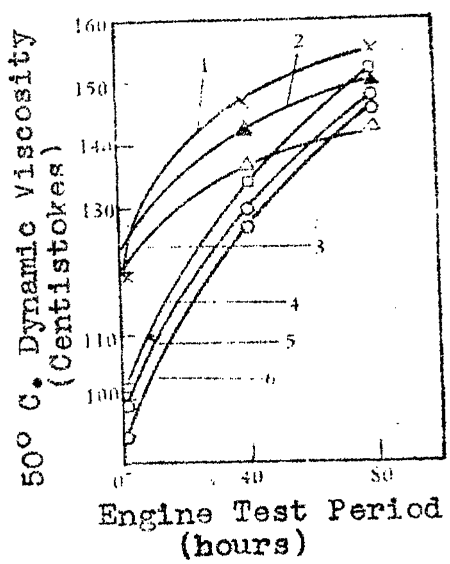
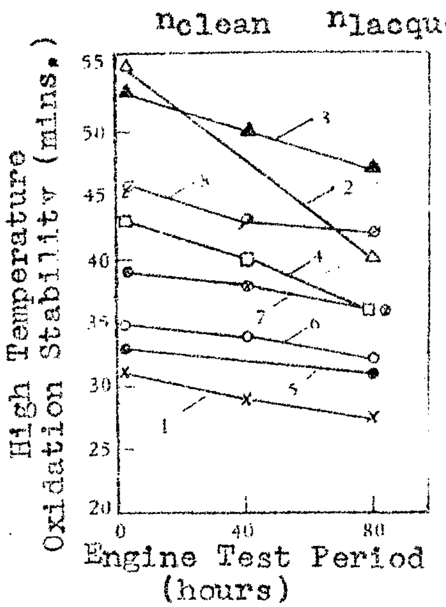


Figure 12. Viscosity of Lubricant Samples After Engine Test.



1. Second Baku Crude-No. 15;
2. Same, With 3%-711A;
3. Same, With 3%-711;
4. Same, With 3%-701;
5. Same, With 3%-AzNII-TsIAT-NIM-1;
6. DP-14
7. Yumen Crude-No. 10;
8. Same, With 3%-711A.

Figure 13. High Temperature Oxidation Stability of Lubricant Sample After Engine Test.

The lacquer film is broken down into seven grades, according to the shade of the film on the piston. Briefly, pistons which are void of lacquer films are graded as 0, those with films of darkest shade are classified as grade 6.

In determining the piston ring stickiness index, n_{ring}, n_{ring} 0 in the case of mobile rings, n_{ring} 0.5 for sticky rings, and for rings under seizure, n_{ring} is calculated according to the following formula:

$$n_{ring} = \frac{\text{angle in degrees of portion of ring under seizure}}{360^\circ} + 0.5$$

The piston ring stickiness index of a piston is equal to the algebraic sum of three rings.

Table 10 (see page 23) shows the test results for carbon dispersion properties and detergency of various oil samples.

The results shown in Table 10 indicate that additive 711A possesses the best detergent (or defluocculant) properties. Detergency of Second Baku Crude-No. 15 after the addition of this additive is superior to that of diesel lubricant DP-14.

Figures 14-17 (see page 24) are photographs of cylinders, showing all four sides, taken after engine tests

Lubricant Sample	n_{carbon}	$n_{lacquer}$	Detergent Property: Stickiness of Piston Ring: No. 1 Ring	No. 2 Ring	No. 3 Ring	n_{ring}	n_{clean}
Second Baku Crude-No. 15	0.91	5.8	0	0.5	0.5	1.0	6.8
Same, With 3%-711A	0.86	2.4	0	0	0	0	2.4
Same, With 3%-711	1.81	3.5	0	0.5	0	0.5	4.0
Same, With 3%-701	1.03	4.5	0	0.5	0	0.5	5.0
Same, With 3%-AzNII-TsIATNIM-1	0.56	5.0	0.7	0	1.2	1.9	6.9
DP-14	1.13	4.0	0.5	0	0	0.5	4.5
Yumen Crude-No. 10	0.57	5.4	0	0	0.5	0.5	5.9
Same, With 3%-711A	1.02	2.2	0	0	0	0	2.2

Table 10.

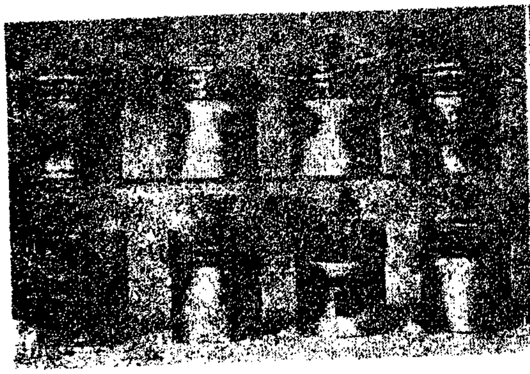


Figure 14. Left-side of Piston Surface.

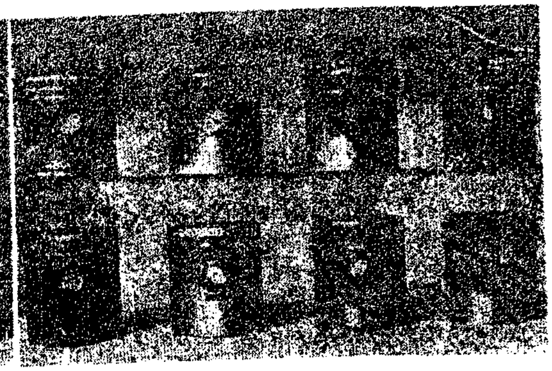


Figure 15. Revolved 90° Clockwise From Original Position.

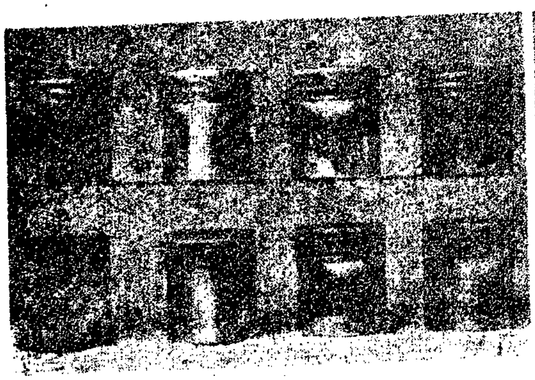


Figure 16. Revolved 180° Clockwise From Original.

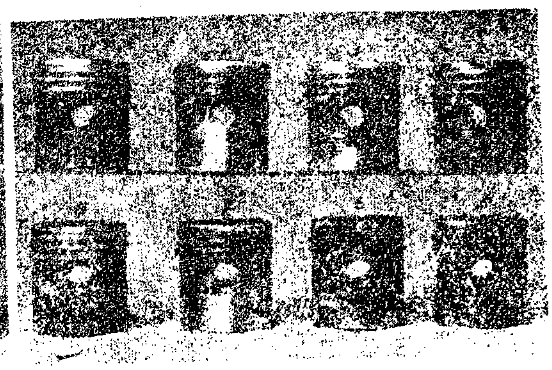


Figure 17. Revolved 270° Clockwise From Original Position.

Legend:
1. Second Baku Crude-No. 15;
2. Same, With 3%-711A;
3. DP-14;
4. Second Baku Crude-No. 15, With 3%-AzNII-TsIATNIM-1;
5. Same, With 3%-701;
6. Same, With 3%-711;
7. Yumen Crude-No. 10, With 3%-711A;
8. Yumen Crude-No. 10.

with various lubricant samples.

AzNII-TsIATNIM-1 is an excellent additive as regards carbon dispersion. This point was also mentioned by Nilchiky[7]. Among the three additives prepared by us, 711A is the best in this property.

On the other hand, however, it was found that carbon accumulation increased when additive 711A was added to Yumen Crude-No. 10.

It was observed that under similar operating conditions, the carbon deposited by various samples differed not only in weight, but in thickness also.

The anti-corrosion and wear-reduction properties of a sample were evaluated by determining the average slope from the wear curves obtained by plotting the decrease in weight of the piston ring, before and after the test, and the iron content of the sample. The effectiveness of these two properties of any motor lubricant is directly demonstrated by the rate of increase of metallic content in the test sample during the course of its actual operation. During the period of lubrication, such metallic substances cannot be differentiated according to their causes -- whether attributed by corrosion or wear -- since these two factors occur simultaneously in the course of the operation. Therefore, the anti-corrosion and wear-reduction properties of a lubricant can be evaluated only together.

The average slope of wear curves is expressed K_{iron}, and the weight-loss of the piston ring is represented by K_{ring}. K_{ring} is the wear rate of one piston ring per unit of time, and is calculated according to the following equation:

$$K_{ring} = \frac{\text{algebraic sum of weight-loss of three piston rings}}{3 \times 80 \text{ hours}}$$

Therefore, its unit is mg./ring-hour.

Table 11 (see page 26) tabulates the wear data of piston rings and the iron content in samples. K_{iron} here is calculated according to Figure 18 (see page 26).

Among these additives, the anti-corrosion and wear-reduction properties of additive 711A are the most outstanding, followed, successively, by 711, 701, and, finally, AzNII-TsIATNIM-1, which are all similar.

Conclusion

1. Additive 711A possesses good detergent properties. When 3% of this additive is added either to Second Baku Crude-No. 15 or to Yumen Crude-No. 10, piston rings

perties of detergency, anti-corrosion, wear-reduction, et cetera.

7. Recently, Puchkov, et cetera, have claimed that oxidation stability of lubricants at high temperatures -- as proposed by Pabock -- lacks unity with those conditions observed in actual performance[11]. However, we are of the opinion that the proposed explanation and the properties observed in actual performance definitely can be correlated.

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10,158

GASIFICATION OF BROWN COAL IN THE GAS PRODUCER OF GENERAL CONSTRUCTION*

-Communist China-

/Following is the translation of an article by Li Ch'en-Hsiang (2621 3819 4382), of Fu-la-erh-chi Plant No. 33, in Jan-liao Hsüeh-pao ('Acta Focalia Sinica', or the Journal of Fuels), Vol. 4, No. 2, pp. 181-184, April 1959./

Based on sound economic and transportation factors, Fu-la-erh-chi Plant No. 33 has been conducting experiments with the gasification of brown coal (low-grade coal from Li-cha-lai-no-erh, Manchuria) in conventional gas producers designed to use bituminous coal. Success finally came after many trials, and the experience would have great significance to all the gas-producer plants across the whole nation. The following is a preliminary report of the results.

I. Gas-producer Design

The gas-producers are of the 3AD-13-Model, suitable for bituminous coal gasification. Among the special characteristics of the gas-producer are automatic coal input, automatic ash removal, automatic rotary ash-tray, and automatic coal distributor. The steam jacket generates steam for use in humidification and air intake. Figure 1 shows the schematic design of the gas-producer.

II. Comparative Characteristics of Natural Coals

Originally, it was planned to use bituminous coal -- from Lao-hu-t'ai (lit., "Old Tiger Terrace"), of Fu-shun. Some of the special points of Lao-hu-t'ai's coal are a low moisture content, a more uniform size, high thermal stabili-

* Received 10 August 1958.

ty, and a high melting point of ash. The special characteristics of the low-grade Cha-lai-no-erh brown coal are a high moisture content, less uniformity (in size), they are highly hygroscopic, they possess an inferior heat stability, and they have a low melting point of ash. The comparative characteristics of the two are tabulated in Table 2.

III. Operating Conditions

Compared to bituminous coals, the principal differences in using brown coals are:

1. Lower temperature in gasifying zone;
2. lower gas-exit temperature;
3. higher air intake and temperature;
4. shallower coal-layer.

These are all due to the characteristics of the brown coal mentioned in the previous paragraph. The operating conditions of Fu-shun bituminous coal and Cha-lai-no-erh brown coal are tabulated in Tables 2-4.

A. The Fu-shun coal flame has a burning period of 1.5-2.5 minutes and an oxidation zone from dark to bright red; the period for brown coal is 3-5 minutes, and the oxidation zone is from light to dark red.

B. The best gas outlet temperature of brown coal is about 200°; considering other factors, the recommended range is 200°-300°.

C. The coal-gas outlet pressure is determined by safety requirements and water-seal characteristics.

D. From practice, the saturation temperature of intake-air ranges from 58°-65° is established. This keeps the oxidation temperature level at approximately 1100°-1200°. After four minutes of glowing, a bright red color is detectable. This guarantees that the ash will not be solidified in the furnace.

E. There should not be any appreciable difference between the flame in the center and that which is at the circumference. This should be kept within 100-150 mm.

F. The percentage of CO_2 in gas produced from brown coal is higher, the CO percentage is lower, due to a lower gasification zone temperature and a thinner coal-layer, and a higher saturation temperature. $Q_H > 1500$ Kcal/m^3. This conforms with coal-gas standards.

IV. Analysis of Characteristics of Brown Coal Gasification

A. Principal furnace and experimental stages and conditions (see Table 5). From Table 5, it is evident that

an increase in the gasifying rate should be accompanied by a rise in the air-input temperature in order to obtain normal operation.

B. Under normal furnace operating conditions -- as indicated in Table 3 -- the pressure drop versus the flow rate is as tabulated in Table 6, and as plotted in Figure 2.

C. Ash characteristics of brown coal:

1. The ashes are finer and these are no large lumps. The finer ash packs tighter in the ash-tray, thus it is not easy to unload. This is especially so when the ash-tray is not rotating and during the warm-up period. See Table 7. Note that variation of ash levels resulted from manual agitation.

2. In insufficient ash removal or uneven combustion there were small unburned pellets in the ash. These pellets were hard, with occasional air bubbles on the surface.

3. Brown coal has a lower ash content. Friction between ash particles is considerable, and the ash layers have to be shifted downward manually. For instance, in the second shifting, the No. 7 port has 700 mm. of ash, while the No. 1 port has 300 mm., the No. 3 port has 250 mm., and the No. 5 port has 400 mm. When the shift was completed, a slight manual agitation reduced the No. 7 port ash level to 300 mm. Then, the radial force in the center pushes the ash outward and there is no problem in ash removal, provided that no pellets form in the ash. This difference in the ease of ash removal between the center and the circumference is graphed in Table 8 for the first shifting of the fourth day. Figure shows a side-view of Ports No. 1 through No. 5.

D. Analysis of draft distribution and flame strength.

1. A particular characteristic of the D-Type gas-producer is its uniformity of air distribution. According to the Soviet Academy of Science, the air rate is still slightly higher at the center than it is at the circumference, the differential is greater with higher rate and higher pressure. So, when normal gasification products decrease, the coal layers in the center must be thicker and the degree of thickness should gradually decrease towards the circumference, forming a bell-shaped conformation, in order to insure even gasification over the entire furnace.

2. In natural draft conditions during the period of warm-up, the uneven draft distribution is not apparent. If the coal-layer is thick in the center, there will be higher gasifying rate at the circumference because of the lower flow resistence in the circumference. The

flame height in the center drops to under 50 mm. As soon as the furnace is operated under normal draft conditions, the flame would become normal.

E. Actual experimental data and material balance. Analysis of experimental data is tabulated in Figures 9-11. Table 12 is material balance data.

Conclusion

This experiment concluded that it is possible to gasify coal of a comparatively low-grade type with lower mechanical strength and heat stability in a conventional gasifier designed for better grade coals. The higher content of moisture of the brown coal results in a lower gas output temperature and less tar content in the gas. Less ash is produced, and the non-pellet-forming and non-solid-forming characteristics of the brown coal greatly reduce manual work requirements. Thus, it is possible to increase production. The fact that viscous particles are not formed in the process, plus the low gasifying temperature, greatly reduces the flow velocity in the gasifier, thus reducing entrainment.

These results support the use of locally-available low-grade coal for gasification, thus conserving valuable bituminous coal for use as a raw material in the chemical industry. This experiment also proves that the use of brown coal, instead of bituminous coal, in gasification, does not require complicated modification in the gasifier.

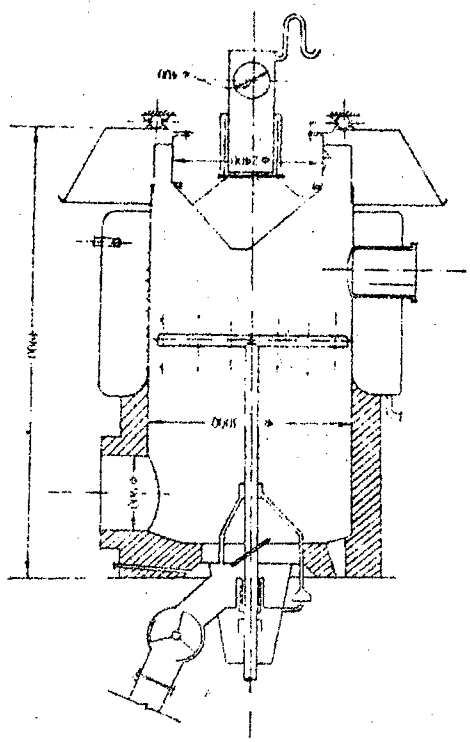

Figure 1. Cross-Sectional View of Soviet 3AD-13-Model Gas Producer.

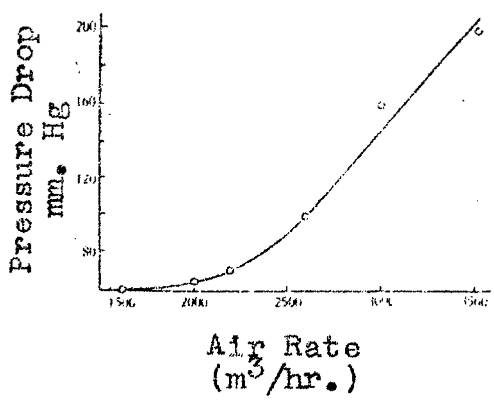

Figure 2. Air Rate vs. Pressure Drop.

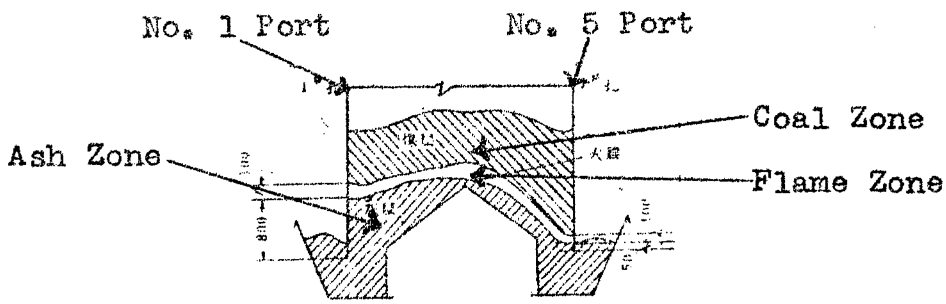

Figure 3. Cross-Sectional View of Coal Distribution.

	Proximate Analysis %			
	Moisture W^p	A Ash Content A^c	Volatility V^c	Fixed Carbon C^c
Bituminous Coal	3.09	8.91	41.81	50.08
Brown Coal	19.17	6.20	49.69	44.11

	Ash Melting Point			Hygroscopic Property
	t_1	t_2	t_3	
Bituminous Coal	1350	1400	1450	not apparent
Brown Coal	1150	1245	1330	high

Table 1. Coal Characteristics

	Air Consumption	Sat'd Air Temperature	Production Capacity
Units	m^3 / Kg coal	C^o	Ton Coal / Hr.-Unit
Bituminous Coal	2~2.1	40~45	2.1
Brown Coal	1.2~1.6	58~65	2.9

Carbon in Ash	Tar	Dust	Water
%	g/m^3	g/m^3	g/m^3
< 15	33.05	4.66	73.02
< 20	7.00	2.14	---

Table 2. Gasifying Conditions

Ultimate Analysis %					Heat Content	
Carbon C^r	Hydrogen H^r	Oxygen O^r	Nitrogen N^r	Sulfu: S^r_{ob}	High Q^r_B	Low Q^r_H
79.77	6.49	10.83	2.10	0.81	--	5137
66.43	7.11	24.52	1.56	0.28	6984	4831

Adhesive Property	Mechanical Strength	Remark
weak	strong	
none	easily broken	W ≅ 35-40%, before exposure to air

Gasifying Efficiency	Gasifying Rate	Air Rate	Gas Rate
$\frac{m^3}{Kg\ Coal}$	$\frac{Kg\ Coal}{m^2\ hr.}$	$\frac{m^3}{hr.}$	$\frac{m^3}{hr.}$
3.1~3.3	~300	4500	~6500
2.0~2.5	~400	4000	~6500

Item	Height of Ash Layer		Height of Flame Layer		Height of Coal Layer		Height of Air Layer		Flame Temp.	Flame Color
	Center	Circ.	Center	Circ.	Center	Circ.	Center	Circ.		
Unit	mm.	mm.	mm.	mm.	mm.	mm.	mm.	mm.	°C	
Bituminous Coal	100 250	500 1000	150	100	600 1000	600 1000	2200 2400	2200 2400	1200 1350	Dark Red
Brown Coal	100 250	300 800	100 150	100 150	400 600	400 600	2800 3000	2800 3000	1000 1200	Black

Gas Outlet Temp.	Gas Outlet Pressure
°C	mm.
450 550	20 80
200 300	20 80

Table 3. Operating Conditions

Composition	CO_2	CO	H_2	CH_4	C_nH_m	O_2	N_2	Q_H
Units	%	%	%	%	%	%	%	$Kcal/m^3$
Bituminous Coal	< 3	> 29	10~12	2~4	0.5~1	0.1~0.2	50	1550~1650
Brown Coal	< 5	> 28	14~18	2 4	0.5~1	0.1~0.2	50	1500~1550

Table 4. Gas Analysis

Table 5. Operational Conditions Under Different Gasification Rates.

Air Intake $\frac{m^3}{hr.}$	Gasifying Rate $Kg/m^2 \cdot hr.$	Saturation Temp. ^oC	Gas Exit Temp. ^oC	Gas Q $\frac{Kcal}{m^3}$	Furnace Conditions
1500	150	45	350	1350	Even combustion, thinner coal layer
2000	200	46	280	1450	Slight pellet forming at circumference
2000	200	50	250	1500	Normal, slightly off-center
2500	250	56	230	1500 1600	Normal
3000	300	58	200	1500 1600	Normal
3500	350	60	200	1500 1600	Normal

Air Rate	$m^3/hr.$	1600	2000	2200	2600	3000	3500
Pressure Drop	mmHg	60	65	70	100	160	200

Table 6. Air Rate vs. Pressure Drop.

Port Number		1	2	3	4	5	6	7	8
1st Day	0-8 hr.	200	350	500	200	700	500	300	---
	8-16 hr.		WARM-UP (Forced Draft						
	16-24 hr.		for two hrs.)						
2nd Day	0-8 hr.		-- Same as Above. --						
	8-16 hr.		-- Same as Above. --						
	16-24 hr.		-- Same as Above. --						
3rd Day	0-8 hr.	250	---	150	---	---	---	---	---
	8-16 hr.	200	500	450	550	100	300	---	1000
	16-24 hr.	800	800	450	600	200	250	400	850
4th Day	0-8 hr.	800	800	1200	850	100	900	750	900
	8-16 hr.	1000	950	950	600	850	500	600	850

Table 7. Ash-Layer Height Variation
at Circumference (mm.).

Port Number	1	2	3	4	5	6	7	8
Center (mm.)	100	200	0	150	50	200	100	200
Circumference (mm.)	800	800	1200	850	100	900	750	900

Table 8. Ash Distribution On
1st Shift-4th Day.

CO_2	C_nH_m	O_2	CH_4	H_2	CO	N_2	Q_H Kcal./m^3
6.00	0.47	0.1	2.2	16.4	27.4	47.52	6532

Table 9. Analysis of Coal-gas Composition (%).

	A	C
Carry-over	44.45	55.55
Ash	76.13	23.87

Table 10. Combustible Matter in Ash and Carry-over (%).

Air Rate	Saturation Temp.	Air Pressure	Gas Temp.	Steam Consumption	Efficiency
$\frac{m^3}{hr.}$	°C.	mm. Hg	°C.	$\frac{Kg}{Kg\ Coal}$	$\frac{m^3}{Kg}$
3500	55	255	218	0.205	2.34

Air Consumption	Gasifying Rate
$\frac{m^3}{Kg}$	$\frac{Kg}{m^3 hr}$
1.4	359

Table 11. Optimum Conditions.

	ELEMENT	C	H	O	N	S	A	TOTAL Kg.
RAW MATERIAL	1. DRY COAL	0.4958	0.0531	0.1837	0.0116	0.0021	0.0620	0.8083
	2. MOISTURE	—	0.0213	0.1895	—	—	—	0.2118
	3. AIR	—	—	0.4064	1.3780	—	—	1.7844
	4. STEAM	—	0.0228	0.1825	—	—	—	0.2058
	TOTAL	0.4958	0.0972	0.9621	1.3896	0.0021	0.0620	3.0094
PRODUCT	1. DRY COAL	0.4563	0.0450	0.6618	1.3892	0.0021	—	2.5544
	2. MOISTURE	—	0.0510	0.4079	—	—	—	0.4589
	3. CARRYOVER	0.0031	0.0004	0.0014	0.0001	—	0.0004	0.0054
	4. TAR	0.0102	0.0008	0.0290	0.0003	—	—	0.0403
	5. ASH	0.0148	—	—	—	—	0.0616	0.0764
	TOTAL	0.4844	0.0972	1.1001	1.3896	0.0021	0.0620	3.1354
	DIFFERENCE	+0.0114	0	−0.1380	0	0	0	−0.1260

Table 12. Material Balance.

10,144

END